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The following are enclosed for filing this nonprovisional application relating to:

INTEGRATED PHOTONIC SWITCH

☐ CONTINUING APPLICATION. This is a ☐ Continuation ☐ Divisional ☐ Continuation-in-part of prior Application No. ________

☐ A Certified Copy of the application(s) from which this application claims priority under 35 U.S.C. §119 has been filed in the prior application identified above.

☐ Copy of assignment(s) to Northern Telecom Limited, recorded with respect to the prior application identified above.

☒ Specification, including Claims and Abstract — Pages: 24

☒ Drawings — Sheets: 5

☒ Oath or Declaration — Pages: 1

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☐ Signed statement attached deleting inventor(s) named in the prior application

☐ The entire disclosure of the prior application is considered as being part of the disclosure of the accompanying application and is hereby incorporated therein by reference.

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Yours very truly
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INTEGRATED PHOTONIC SWITCH

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates to optical switches and is particularly concerned with switching optical signals composed of light of predetermined wavelengths, for example, Wavelength Division Multiplexed (WDM), Dense WDM (DWDM), or Coarse WDM (CWDM) optical signals used in optical telecommunications.

Background Art

Optical transmission systems achieve their end-to-end connectivity by concatenating multiple spans between intermediate switching nodes. When the end-to-end granularity of any given transmission path is a fraction of the capacity of a given optical carrier, time division multiplexing (TDM) protocols are applied, which share the overall bandwidth of a carrier signal. In this case, the individual signals (tributaries) are switched electronically at the intermediate nodes, since individual tributaries can only be accessed by demultiplexing the TDM signal.

On the other hand, Wavelength Division Multiplexing (WDM), and particularly DWDM and CWDM transmission can provide manifold capacity expansion on existing fibre links. DWDM optical networks transmit multiple channels (wavelengths) on each optical fiber in the network. The result is a plurality of channels on each fiber, a channel carrying information between two terminals in the networks. An advantage of the WDM networks is that conversions between the optical and electrical domains take place practically only at the periphery of the transport network. The signals are add/dropped and amplified within the network in optical format.

However, current WDM optical networks typically convert channel signals into electrical signals at every switching node in the network because optical switches having sufficiently large enough port counts are

not available, nor is optical reach sufficient. Conversion is performed using transmitters (Tx), receivers (Rx), transceivers (Tx-Rx pair) or transponders at every port of the switching node, and for every channel. (Transponders are devices that convert the signal between the optical and electrical domains, and also translate the wavelength of the channels at the border between the long and short reach networks.)

These converters are expensive. As the number of channels carried by an optical fiber increases, the required accuracy of the converters also increases, and hence the cost. Moreover, as the number of ports per switching node increases, the required number of converters also increases. Consequently, large networks carrying dense DWDM signals require many costly converters and are therefore costly to build.

There is a substantial advantage in designing optical transmission networks such that the majority of the channels (wavelengths) can be routed end-to-end via optical switches and optical amplifiers, without the use of converters (e.g. transponders) on a per channel wavelength basis at intermediate sites or nodes. This leads to a need for an optical cross-connect switch optimized for routing wavelengths from end to end, as opposed to a large opaque optical switch fabric placed between banks of transponders.

There are proposals to build large, purely optical switches that offer full connectivity between all their ports. However, fabrication of these large optical switches has proven difficult. Currently, large non-blocking optical switches use a large number of switch modules. One example of this envisages building a 128 port x 128 port switch out of three stages of multiple 16 x 16 crosspoint matrices, or a 512 x 512 port switch out of three stages of multiple 32 x 32 crosspoint matrices, in a three stage CLOS architecture. The above is based on the availability of 16 x 16 or 32 x 32 switch matrices in the form of Micro-Electro-Mechanical (MEM) switch matrices (described in e.g. "Free-space Micromachined Optical-Switching Technologies and Architectures", Lih Y. Lin, AT&T Labs-Research, OFC99 Session W14-1, Feb. 24, 1999).

Other multi-stage approaches use smaller matrices and more stages. Even the 3 stage CLOS architecture is limited to 512-1024 switched wavelengths with 32x32 switch matrix modules, which, in today's 160 wavelength per fiber DWDM environment, is only adequate to handle the output/input to 3 fiber pairs (480 wavelengths). In addition, current multi-stage switches have significant problems, even at three stages. These problems include high overall optical loss through the switch, since the losses in each stage are additive across the switch, and there is the potential for additional loss in the complex internal interconnect between the stages of the switch. Size limitations in terms of the number of wavelengths switched can be overcome by going to a five stage CLOS switch, but this further increases the loss through the switch as well as it adds to its complexity and cost. In addition, a CLOS switch requires a degree of dilation (i.e. extra switch paths) to be non-blocking and each optical path has to transit three (or five) individual modules in series.

MEM mirrors technology has evolved lately. The '3-D MEMS' devices have emerged as the photonic switch technology of choice for large fabric switches. 3-D MEMS is a term used by the Applicant for a mirror mounted on a frame that can be rotated along two axes, giving it four degrees of freedom. The 3-D MEMS devices are arranged preferably in a matrix, which comprises besides the mirrors a control system for positioning the mirrors independently.

SUMMARY OF THE INVENTION

It is an object of the invention to provide an integrated photonic switch that alleviates totally or in part the drawbacks of the current switches.

Another object of the invention is to provide a photonic switch for use in WDM/DWDM/CWDM networks, which switches individual wavelengths (channels) for a certain input fiber to a selected output fiber.

According to one aspect of the invention there is provided a photonic switch for a DWDM network comprising, a plurality *I* of input ports and a plurality *I'* of output ports, an optical demultiplexer for

separating said wavelength λ_K from an input multichannel signal Sin(k,i) received on an input port *i*, and directing same on an assigned ingress area along a predetermined input path, a switching block for directing a wavelength λ_K along an optical path from an assigned ingress area to an associated egress area selected from a plurality of egress areas, and an optical multiplexer for directing said wavelength λ_K from said associated egress area along a predetermined output path, and combining same into an output multichannel signal Sout (k',i'), transmitted on a port *i'*.

According to further aspect of the invention, there is also provided a method of routing a wavelength within a photonic switch of a DWDM network, comprising, pre-establishing an input optical path between an input port associated with said wavelength and an assigned optical switching element of an input matrix, according to a connectivity map, establishing an adaptable path from said assigned optical switching element to an associated optical switching element of an output matrix; and pre-establishing an output optical path between said associated optical switching element and an output port of interest according to said connectivity map.

In yet another aspect of the invention there is provided a photonic switch for routing a plurality of wavelengths of a DWD transport network, between a plurality of input ports and a plurality of output ports comprising, an all-optical switch fabric for cross-connecting a wavelength λ_K from an optical input multichannel signal Sin(k,i) to an optical output multichannel signal Sout(k',i'), along an adaptable optical path, and a control unit for configuring said adaptable optical path.

The invention provides a cost-effective, low-loss system of providing wavelength interchange between multiple WDM line systems. Photonic switch according to the invention is also a key enabler for ultra long-reach networks, as it can provide availability and flexibility benefits without conversion of the signals between the optical and electrical domain.

Looking at a photonic switch node, this invention provides significant savings in, or elimination of, filters, amplifiers, connectors, patch-cords, fiber shuffles. Also, the savings in fiber management operations (footprint, power, set-up time, etc) could be important.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other objects, features and advantages of the invention will be apparent from the following more particular description of the preferred embodiments, as illustrated in the appended drawings, where:

Figure 1 shows a portion of an optical network with electrical cross-connects;

Figure 2 shows the block diagram of an optical network with photonic switching according to the invention;

Figure 3A is a diagram of one plane for an embodiment of the photonic switch;

Figure 3B is a spatial view of the embodiment in Figure 3A showing a switching operation;

Figure 3C is a spatial view of an embodiment of the photonic switch with add/drop capabilities;

Figure 4A is a diagram of another embodiment of the photonic switch; and

Figure 4B is a side view of the embodiment in Figure 4A.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Figure 1 shows a portion of an unidirectional optical network **1**, connecting two path terminals **A** and **B**. Network **1** includes two switch sites **C** and **D**, and a regenerator site **E**, interconnected by spans of optical fibers. Optical amplifiers **7** are spaced apart at appropriate intervals along the spans, for amplifying all the individual channels in the WDM signal, without conversion.

The terminal at site **A** converts a plurality of electrical signals input to the optical network **1** to optical signals, and combines the optical

signals into a WDM signal. At the far end **B**, the WDM signal is demultiplexed into individual optical signals, which are converted back to electrical signals.

Switch sites C and D are provided with electrical cross-connects **2** and respectively **2'**. An electrical cross-connect (switch) **2, 2'** comprises at the input side, an optical demultiplexer **4, 4'** coupled to an electrical switch fabric **6, 6'**. The signals are independently cross-connected between the input and output ports by switch fabric **6, 6'**, as needed. An optical multiplexer **5, 5'** is coupled at the output side of the electrical switch fabric **6, 6'**. Switch node **C** is also provided with an optical add/drop multiplexer (OADM) **3** for effecting add/drop operations. Namely, OADM **3** separates the traffic addressed to a local user (drop operation) and adds local traffic at the output of the switch, for a remote user (add operation). Similarly, OADM **3'** effects add/drop operations at node **D**.

As conversion of signals is necessary before and after switching, sites **C** and **D** must be provided with transponders **T** for each channel for O/E and E/O conversion, respectively. It is to be noted that blocks marked **T** in Figure 1 are not necessarily transponders, they could be transceivers, i.e. receiver-transmitter (Rx-Tx) pairs, without frequency translation. As well, for the example of Figure 1 (unidirectional flow of traffic), these blocks assume the role of a receiver at the input side of the signal and a transmitter at the output side, as appropriate.

Currently, demultiplexing, multiplexing and add/drop operations are effected with filters and patchcords between the switch and the filter for each wavelength, resulting in a high loss through sites **C** and **D**. An optical pre-amplifier **7a** is generally provided at the input of demultiplexer **4, 4'** to amplify the received WDM signals before switching. Similarly, a post-amplifier **7b** is generally provided at the output of multiplexer **5, 5'** to amplify the transmitted WDM signals after switching.

Network **1** also requires signal regeneration. A regenerator site, such as site **E** is generally provided with repeaters **3** comprising

demultiplexers **4"** coupled to multiplexers **5"** via regenerators **R**. This site also requires an additional pair of transponders per channel signal, (not shown, being included in the regenerators **R**).

To summarize, it is apparent that current WDM configurations require a pair of transponders at each site for each channel signal passing through switches **2, 2'**. Further, additional transponders are required to add or drop channel signals to/from the switch **2**. Network **1** also requires regeneration of the signals. Furthermore, any increase in the number of channels (wavelengths) in a WDM signal requires an additional pair of transponders in every switch **2** and every repeater **3**.

Figure 2 shows a network **100** using a photonic switch according to the present invention. It is evident that since the switching and the add/drop operations are effected in the optical domain, no transponders are necessary, resulting in important saving of equipment at the switching nodes **C** and **D**, as well as a lower loss.

The photonic switch **9, 9'** at sites **C** and respectively **D** comprises a demultiplexer **40, 40'**, a multiplexer **50, 50'** and a switching block **8, 8'**. The switching block includes switch fabric **14**, made for example of 3D-MEMS matrices. However, the configuration of the switch fabric **14** according to the invention is not limited to using 3D-MEMS devices; any other devices able to redirect the light with more than four degrees of freedom can equally be used for the switch fabric **14**.

Switching block **8, 8'** also has a control unit **13, 13'** for controlling the path of the wavelengths within the switch fabric from the input ports (connectors) to the output ports, by adequately orienting the 3D-MEMS devices.

The input span **11** and output span **12** in Figure 2 comprise a plurality of input and output fibers and the associated ports, each carrying a respective multi-channel (DWDM) input/output optical signal. The number of the input ports is generally equal with the number of the output ports, but it could also be different in some applications. Therefore, we note here the total number of input ports with *I* and the number of output ports with *I'*, so that an input port is designated by index *i* and an output

port by index *i*. We also denote the maximum number of channels (wavelengths) on an input port with *K*, the maximum number of channels (wavelengths) on an output port with *K'*, the range of an input channel on a port with *k*, and the range of an output channel on a port with *k'*. In this way, an input multichannel signal is denoted with Sin(k,i) and an output multichannel signal is denoted with Sout(k',i').

The switch node **C**, **D** may also be provided with pre-amplifiers, such as **7a**, and post-amplifiers, such as **7b**, depending on the specifics of the application.

Photonic switches **9** and **9'** shown in Figure 2 have a different structure and mode of operation form the electrical cross-connects at nodes **C** and **D** in Figure 1. Besides the differences in the configuration and mode of operation of the switch fabric **14**, the optical demultiplexer **40** and multiplexer **50** have also a different structure than the demultiplexer **4** and multiplexer **5** shown in Figure 1. Also, the photonic switch **9, 9'** performs add/drop operations in a specific way, without the need of individual OADM's such as **3, 3'**. This arrangement results in a significantly lower loss through the photonic switch than in the current arrangement of fiber patchcords for every wavelength.

Figure 3A is a diagram of an embodiment of the photonic switch **9**, which is shown in a spatial view in Figures 3B and 3C. Figures 3A-3C do not illustrate the control unit **13** and some optical elements that are not relevant to the ensuing description.

Also, Figure 3A is intended to show how the wavelengths are demultiplexed at the input side of the switch and multiplexed at the output side. As indicated above, the total number of input ports (fibers) is denoted with *I* and the number of output ports with *I'*, so that the input fibers (ports) are denoted with **11-1**...**11-i**...**11-I** and the output fibers (ports) are denoted with **12-1, ... 12-i', ...12-I'**. For simplicity, this drawing shows four input wavelengths and four output wavelengths in one plane of the switch. The wavelengths input on fiber **11-1** in this example are output on fiber **12-2**. In fact the switch operates according to a wavelength map which results in moving some wavelengths from an input

multichannel signal to an output multichannel signal, so that the wavelengths are grouped (multiplexed) differently in the input and output signals. This is shown explicitly in Figure 3A and 3B, described later.

The switch fabric **14** comprises in this embodiment two matrices of 3-D MEMS devices **10** and **20** arranged in two planes. A 3-D MEMS device is identified within the respective matrix by a row number (*k)* and column number (*i*). Thus, mirror **4/3** is located in the row 4 and column 3 of the matrix **10.** The matrices need not necessarily be parallel to each other, as long as the trajectory of each wavelength is carefully engineered as described in the following.

The example of Figures 3A, 3B and 3C is for *I=I'=4, and K=K'=4.* It is to be understood that the number of fibers and of wavelengths are by way of example only, and that the photonic switch can cross-connect a much larger number of wavelengths between a larger number of fibers.

At the input side of the switch **9**, input signal Sin(k,i), here Sin(4,1) received on input fiber **11-1** is separated into four component wavelengths (K=4) by demultiplexer **40**, as also shown in Figure 2. The demultiplexer is in this example a diffraction grating **40.** Fiber **11-1,** as well as all remaining input fibers, is aligned to direct the incoming light on collimating lens **16,** which in turn directs the wavelengths on diffraction grating **40** on a certain area (spot) noted with **a**, and at an angle of incidence α. The term spot is used herein to define the area of incidence of a beam of light, as shown in Figure 3A by letters **a** and **b**, and as intuitively shown for example in Figure 3B by dotted circles marked **a1** to **a4** and **b1** to **b4**.

The diffraction grating **40** reflects each wavelength in the incoming signal Sin(4,1) on a certain 3-D MEMS device of matrix **10**, at an angle of incidence β. The input fiber/port **11-1**, diffraction grating **40** and matrix **10** are placed in a predetermined relationship with respect to each other by pre-setting angles α and β. The angles may be pre-set so that each wavelength input from fiber **11-i** is incident on a mirror in length *i*, e.g. $\lambda1$ is received on mirror **1/i**, $\lambda2$ on mirror **2/i**, ... λk on mirror **k/i**, ... and λK on

mirror **K/i**. Preferably fiber **11-1** is associated with column i=1, fiber **11-2** with column i=2, etc.

In turn, the mirrors of array **10** direct the respective incident wavelength on a target mirror of MEMS matrix **20**. In the example of Figure 3A, mirror **1/1** sends λ1 on mirror **2/1'** of MEMS array **20**, mirror **1/2** sends λ2 on mirror **2/2'**, mirror **1/3** sends λ3 on mirror **2/3'** and mirror **1/4** sends λ4 on mirror **2/4'**. As the mirrors can rotate about two axes, each mirror can redirect wavelength λ1 on any mirror of matrix **20** according to the position of mirror in matrix **10** its orientation (angle β). Angle β may be adjusted as needed by control unit **13**.

Mirrors of matrix **20** can also rotate about two axes, and each mirror is set to redirect the light towards multiplexer **50**. The angle γ varies with the position of the mirror in matrix **20**, angle β, and the orientation of the mirror. The orientation of the 3-D MEMS devices in the matrix **20** is adjusted as needed by control unit **13**.

Diffraction grating **50** operates as a multiplexer, in that it combines light beams into an output multichannel signal Sout(k',i'), here Sout(4,2) according to the wavelength and the spot of incidence **b**, and directs signal Sout(4,2) on a respective output fiber **12**. Again, the wavelength - output port-mirror assignment is preferably predetermined.

The output of the photonic switch **9** is also provided with a focusing lens **17**, for focusing the wavelengths form spot **b** on the fiber **12-2**.

It is to be understood that other passive optical elements such as connectors, lenses, etc. may be provided for adjusting the light trajectories in the switch **9**. Such elements are however not shown or described, as they are well known to persons skilled in the optical physics, and also as they are not relevant to the principle of operation of the present invention.

To summarize, there are constrains between the diffraction gratings **40** and the matrix **10**, and between diffraction gratings **50** and matrix **20**. As light from the input fiber **11-1** hits grating **40**, it is split into its component wavelengths. In order to position the matrix **10** in relation to the gratings **40**, the component wavelength map must be known in

advance. If the wavelengths change, the mirrors would be out of position. However, as there exists standard wavelengths maps (defined by ITU), this should not occur. If a mirror in matrix **10** has been properly positioned to reflect a particular wavelength, only that wavelength can be incident on that mirror.

The reverse is true for the positioning of mirrors in matrix **20** that direct wavelengths to the grating **50** which multiplexes them up and directs them to the output fibers. If a wavelength is incident on a mirror in matrix **20** that is not the correct wavelength, as defined by the geometry of the mirror, grating and output port, it cannot be directed to the output port. This is actually an advantage of the arrangement in the invention, as it disallows equivalent wavelengths from being directed onto the same output fiber. It also avoids interference with other channels in the event a channel wanders from its center wavelength.

Figure 3B shows a perspective view of a switch fabric with 3-D MEMS matrices **10** and **20**, for switching 4-channel signals input on four fibers **11-1** to **11-4** to output fibers **12-1** to **12-4**. The control unit, the focusing lens and collimating lens are not illustrated, for simplification.

Since the number of wavelengths and of the ports is four in this example, each matrix has 4x4 3-D MEMS devices. Four input fibers and four output fibers are shown, each carrying 4 wavelengths. Clearly, matrices with more/less mirrors may equally be used, according to the application. It is also possible to have differently sized first and second matrices. In the general case, for *I* input fibers, and *I'* output fibers, a maximum of *K* wavelengths on each input fiber and K' on each output fiber, matrix **10** has *I* columns and *K* rows, and matrix **20** has *K' rows and I' columns.*

The demultiplexer **40** receives the input DWDM signals from the input fibers and separates each DWDM signal into component channels (wavelengths). Thus, the multichannel signal Sin(4,1) from fiber **11-1** is directed on spot **a1**, the multichannel signal Sin(4,2) from fiber **11-2** is directed on spot **a2**, etc. A channel λk of Sin(k,i) is directed on a first 3-D MEMS mirror **k/i** of the first matrix **10**, according to the port (i) on which it

arrives at the switch, and the position of spot **a** and the wavelength λk. In Figure 3B, wavelength λ3 arriving to the photonic switch **9** over fiber **11-3** is directed by diffraction grating **40** from spot **a3** onto first mirror **3/3**.

From matrix **10**, the wavelength is reflected towards a mirror in matrix **20**. The second mirror is selected in matrix **20** by the control unit **13**, which adjusts the orientation β of the first mirror, according to the current wavelength map. Each mirror of matrix **20** directs the channel incident on it towards the multiplexer **50** on one of spots **b-1** to **b-4**, depending on the β of the first mirror, the position of the second mirror in matrix **20**, and the orientation γ of the second mirror. In Figure 3B, wavelength λ3 is reflected by mirror **3/3** on mirror **1/2'**, which in turn directs this wavelength on diffraction grating **50** spot **b-1**, for multiplexing it with other wavelengths arriving on spot **b-1** and intended to travel over fiber **12-1**.

Figure 3C shows a spatial view of a photonic switch **9** with integrated add/drop, and examples of add and drop operations. It is again noted that according to the invention, there is no need to provide a separate OADM. 3D-MEMS matrix **15** provides the add functionality, while 3D-MEMS matrix **25** provides the drop functionality. The matrices **15** and **25** have an extended number of columns, namely they have in the example of Figure 3C two additional columns 5 and 6, which could serve 2x4 add ports **21** and 2x4 drop ports **22** respectively. The fibers/ports receiving the add channels are denoted with **A1-A8** on Figure 3C, whnd the fibers/ports transmitting the drop channels are denoted with **D1-D8**. The add/drop operations use these zones, and therefore the zone on matrix **15** defined by rows 1-4 an columns 5, 6 is the add zone, while the zone on matrix **25** defined by rows 1'-4' an columns 5', 6' is the drop zone. The remaining area (rows 1-4, columns 1-4) on each matrix is defined as the switching zone.

The example in figure 3C shows an add channel of wavelength λ_{add} received on fiber **A2** of add ports **21**. The channel is directed from port **A2** on mirror **5/2** (shown in dark grey) of add/drop zone of matrix **15**, from

where it is reflected on mirror **2/3'** (also shown in dark grey) of matrix **25**. Mirror **2/3'** directs the add channel to diffraction gratings device **50** on area **b2** so that add channels λ_{add} is multiplexed over the output fiber corresponding to spot **b2**, here fiber **12-2**.

A drop operation is effected in a similar way. For example, a drop channel λ_{drop} is separated from the input DWDM signal received from input fiber **11-1** by diffraction gratings device **40**, which directs this channel from spot **a1** to a first mirror **1/3** (shown in light grey) within the switching zone of matrix **15**. This first mirror directs the drop channel on a mirror in the drop zone of the matrix **25**, which is mirror **5/2'** (also shown in light grey). Then mirror **5/2'** directs the wavelength λ_{drop} to the drop port **D1**.

It is possible to have differently sized add/drop zones on the first and second matrices. In the general case, for an add zone with *m* rows and *n* columns, there will be *m* add ports (fibers), and a maximum of *n* wavelengths on each add fiber. For a drop zone with *m'* rows and *n'* columns, there will be *m'* drop fibers, and a maximum of *m'* wavelengths on each fiber.

Figure 4A is a schematic diagram of another embodiment of the photonic switch **9** according to the invention, and Figure 4B is a side view of the embodiment in Figure 4A. Control unit **13** is not illustrated for simplification. As well, these figures do not illustrate add/drop operations.

The diagram of Figures 4A and 4B show optical elements similar to those in Figure 3A, namely the collimating and focusing lenses **16** and **17**, demultiplexer **40** and multiplexer **50** in the form of diffraction gratings devices, and the 3D-MEMS matrices **10** and **20**. This embodiment comprises an additional diffraction grating device **14** arranged in the path of the light between the two matrices **40** and **50**. Although the matrices are illustrated in the same plane, it is apparent that they need not necessarily be co-planar.

In this example there are eight input fibers **11-1** to **11-8** and eight output fibers **12-1** to **12-8** *(l=l'= 8)*, each carrying four channels $\lambda 1$ to $\lambda 4$

($k = 4$). An input signal Sin(k,i) from an input fiber **11-i** is collimated with the respective lenses **16-1** to **16-8**, while an output signal Sout(k',i') is focussed on the output fibers **12-1** to **12-8** by focusing lens **17-1** to **17-8**. It is to be understood that the number of fibers and of wavelengths are by way of example only, and that the photonic switch can cross-connect a much larger number of wavelengths between a larger number of fibers.

The DWDM signal collimated by lenses **16** is directed onto diffraction gratings device **40**, which separates (demultiplexes) the wavelengths, and directs each wavelength on a 3-D MEMS mirror of array **10**. The wavelength-input port-mirror assignment is preferably predetermined as discussed in connection with the example of Figures 3A-3C.

The wavelength $\lambda1$ arrives in the example of Figures 4A and 4B on mirror **1/1** of array **10**. Mirror **1/1** directs this wavelength on intermediate diffraction gratings device **14,** and from there $\lambda1$ arrives on a mirror of 3-D MEMS array **20**. As the mirrors can rotate about two axes. Diffraction gratings device **14** may receive wavelength $\lambda1$ on four different areas of incidence **b**, each corresponding to a different angle of incidence β, according to the position of mirror in matrix **10** and its orientation.

Diffraction gratings device **14** reflects the light of wavelength $\lambda1$ on a mirror of array **20**, depending on the angle β and area of incidence **b**, which as seen above, depends on the orientation of mirror **1/1**. Let's say that $\lambda1$ arrives on mirror **3/1** of array **20**, as shown in Figure 4B. Mirror **3/1** now directs the light of wavelength $\lambda1$ on the diffraction gratings device **50** at an angle of incidence γ and on an area of incidence **c**. Angle γ and area **c** depend again on the position of mirror **3/1** in the matrix **20** and its orientation, and can assume different values, as mirror **3/1** may assume different orientations.

Device **50** reflects the light incident on it at an output angle δ to focusing lens **17-3**, and from there to output fiber **12-3**. In the example of Figure 3B, wavelength $\lambda3$ is combined with $\lambda1$ by device **50**, as these

wavelengths are directed by the respective mirrors in matrix **20** onto fiber **12-3**.

Using two matrices of switches, each wavelength $\lambda 1$ can be switched form e.g. fiber **11-1** on any of output fibers **12-1** to **12-8**. On Figure 3B, $\lambda 1$ enters the switch on fiber **11-1**, and exits the switch on fiber **12-3**.

While the invention has been described with reference to particular example embodiments, further modifications and improvements, which will occur to those skilled in the art, may be made within the purview of the appended claims, without departing from the scope of the invention in its broader aspect.

WE CLAIM:

1. A photonic switch for a DWDM network comprising:

a plurality *I* of input ports and a plurality *I'* of output ports;

an optical demultiplexer for separating said wavelength λ_K from an input multichannel signal Sin(k,i) received on an input port *i*, and directing same on an assigned ingress area along a predetermined input path;

a switching block for directing a wavelength λ_K along an optical path from an assigned ingress area to an associated egress area selected from a plurality of egress areas; and

an optical multiplexer for directing said wavelength λ_K from said associated egress area along a predetermined output path, and combining same into an output multichannel signal Sout (k',i'), transmitted on a port *i'*.

2. A photonic switch as claimed in claim 1, wherein said switching block comprises:

a switch fabric for cross-connecting said wavelength λ_K from said input multichannel signal Sin(k,i) to said output multichannel signal Sout(k',i'); and

a control unit for selecting said associated egress area and configuring adjust said switch fabric to direct said wavelength along an adaptable path between said assigned ingress area and said associated egress area.

3. A photonic switch as claimed in claim 2, wherein said switch fabric comprises an input matrix with *K* rows and *I* columns of input optical switching elements, and an output matrix with *K'* rows and *I'* columns of output optical switching elements;

wherein each input port is associated with a column of said input matrix and each wavelength arriving on said input port is associated with a row of said input matrix, and

wherein each said output port is associated with a column of said output matrix and each wavelength transmitted at said output port is associated with a row of said output matrix.

4. A photonic switch as claimed in claim 3, wherein said switching elements have minimum four degrees of freedom of orientation.

5. A photonic switch as claimed in claim 3, wherein said switching elements are 3-D MEMS mirrors.

6. A photonic switch as claimed in claim 3, wherein said optical demultiplexer and said input ports are arranged in a predetermined position relative to each other along said predetermined input path, for separating each input multichannel signal into component wavelengths according an area of incidence of said input multichannel signal on said demultiplexer.

7. A photonic switch as claimed in claim 6, wherein said demultiplexer and said input matrix are arranged in a predetermined position relative to each other along said predetermined input path, for directing each said component wavelength from said demultiplexer to said input matrix according to said wavelength λ_K and said input port i.

8. A photonic switch as claimed in claim 1, further comprising optical elements arranged along said first predetermined input path for directing said wavelength from said input port i on said assigned ingress area.

9. A photonic switch as claimed in claim 3, wherein said multiplexer and said output ports are arranged in a predetermined position relative to each other along said predetermined output path, for combining all wavelengths arriving in a certain area of incidence on said multiplexer within an output multichannel signal.

10. A photonic switch as claimed in claim 9, wherein said demultiplexer and said output matrix are arranged in a predetermined position relative to each other along said predetermined output path, for directing each said wavelength λ_K from said output matrix to said certain area of incidence according to said wavelength • $_K$ and said input port *i*.

11. A photonic switch as claimed in claim 10, further comprising optical elements arranged along said second predetermined path for directing said wavelength from said egress area on said associated output port.

12. A photonic switch as claimed in claim 2, wherein *I=I'* and *i=i'*.

13. A photonic switch as claimed n claim 2, wherein *K=K'*, *k=k'*, *I=I'* and *i=i'*.

14. A photonic switch as claimed in claim 1, wherein said switching block comprises:

a switch fabric for cross-connecting said wavelength λ_K from said input multichannel signal Sin(k,i) to said output multichannel signal Sout(k',i') and for cross-connecting an add wavelength incident on said add zone to said output multichannel signal; and

a control unit for configuring said switch fabric to direct said wavelength along an adaptable path between said assigned ingress area and said associated egress area, and configuring said switch fabric to

direct said add wavelength along an adaptable add path between said add zone and said associated egress area.

15. A photonic switch as claimed in claim 14, further comprising a plurality of add ports.

16. A photonic switch as claimed in claim 15, wherein said switch fabric comprises an input matrix with an input switching zone of K rows and I columns of input optical switching elements and an add zone of M rows and N columns of input optical switching elements,

wherein each input port is associated with a column of said switching zone and each wavelength is associated with a row of said switching zone, and

wherein each add port is associated with a column of said add zone and each wavelength arriving on said add port is associated with a row of said add zone.

17. A photonic switch as claimed in claim 1 wherein said switching block comprises:

a switch fabric for cross-connecting said wavelength λ_K from said input multichannel signal Sin(k,i) to said output multichannel signal Sout(k',i') and for cross-connecting drop wavelength from said input multichannel signal on said drop zone; and

a control unit for configuring said switch fabric to direct said wavelength along an adaptable path between said assigned ingress area and said associated egress area and for directing said drop wavelength along an adaptable drop path between said assigned ingress area and said drop zone.

18. A photonic switch as claimed in claim 1, further comprising a plurality of drop ports.

19. A photonic switch as claimed in claim 18, wherein said switch fabric comprises an output matrix with *K'* rows and *I'* columns of output optical switching elements and a drop zone of *M'* rows and *N'* columns of output optical switching elements,

wherein each said output port is associated with a column of said switching zone and each said wavelength is associated with a row of said switching zone, and

wherein each drop port is associated with a column of said drop zone and each wavelength arriving on said drop port is associated with a row of said drop zone.

20. A method of routing a wavelength within a photonic switch of a DWDM network, comprising:

pre-establishing an input optical path between an input port associated with said wavelength and an assigned optical switching element of an input matrix, according to a connectivity map;

establishing an adaptable path from said assigned optical switching element to an associated optical switching element of an output matrix; and

pre-establishing an output optical path between said associated optical switching element and an output port of interest according to said connectivity map.

21. A method as claimed in claim 20, further comprising transiting said adaptable route to connect said assigned optical switching element to another optical switching element of said output matrix, whenever said connectivity map changes.

22. A photonic switch for routing a plurality of wavelengths of a DWD transport network, between a plurality of input ports and a plurality of output ports comprising:

an all-optical switch fabric for cross-connecting a wavelength λ_K from an optical input multichannel signal Sin(k,i) to an optical output multichannel signal Sout(k',i'), along an adaptable optical path; and

a control unit for configuring said adaptable optical path.

23. A photonic switch as claimed in claim 22 further comprising an optical demultiplexer for separating said wavelength λ_K from said optical input multichannel signal and directing same on an assigned ingress area of said switch fabric along a predetermined input path.

24. A photonic switch as claimed in claim 23, further comprising an optical multiplexer for receiving said wavelength λ_K received along a predetermined output path from an associated egress area of said switch fabric, and combining same with said multichannel output signal.

25. A photonic switch as claimed in claim 22, wherein said all-optical switch fabric comprises an input matrix of *K* rows and *I* columns of optical switching elements, wherein each input port is associated with a column of said input matrix, and each wavelength is associated with a row of said input matrix.

26. A photonic switch as claimed in claim 25, wherein said all-optical switch fabric further comprises an output matrix of *K* rows and *I* columns of optical switching elements, wherein each output port is associated with a column of said output matrix and each wavelength is associated with a row of said output matrix.

27. A photonic switch as claimed in claim 22, wherein said all-optical switch fabric comprises an input matrix with a switching zone of *K* rows and *I* columns of optical switching elements, and an add zone of *M* rows and *N* columns of input optical switching elements,

wherein each input port is associated with a column of said input matrix, and each wavelength is associated with a row of said input matrix, and

wherein each add port is associated with a column of said add zone and each wavelength arriving on said add port is associated with a row of said add zone.

28. A photonic switch as claimed in claim 22, wherein said switch fabric comprises an output matrix with *K'* rows and *I'* columns of output optical switching elements, wherein each said output port is associated with a column of said output matrix, and each said wavelength is associated with a row of said output matrix.

29. A photonic switch as claimed in claim 22, wherein said switch fabric comprises an output matrix with a switching zone of *K'* rows and *I'* columns of optical switching elements, and a drop zone of *M'* rows and *N'* columns of optical switching elements,

wherein each said output port is associated with a column of said switching zone and each said wavelength is associated with a row of said output matrix, and

wherein each drop port is associated with a column of said drop zone and each wavelength arriving on said drop port is associated with a row of said drop zone.

30. A photonic switch as claimed in claim 3, wherein said input and said output matrices are arranged in two different planes.

31. A photonic switch as claimed in claim 30, wherein said planes are substantially parallel to each-other.

32. A photonic switch as claimed in claim 3 wherein said input and output matrices are arranged substantially in the same plane and wherein said switch block further comprises directing means arranged in the path of the light between said input and output matrices.

Abstract

The integrated photonic switch can be used in all-optical networks. incoming multiplexed signals from a number of input fiber ports are separated into their component wavelengths. Individual wavelengths are switched within the switch fabric towards the desired output, and the wavelengths are then multiplexed into WDM signals directed to the appropriate output ports. The multiplexer and demultiplexer are diffraction grating devices, integrated with the switch fabric. The switch fabric includes two matrices of 3-D MEMS mirrors arranged in the same plane, or in two parallel planes. The optical path between the input ports, the demultiplexer and the input matrix is pre-set so that each wavelength is incident on a certain mirror. Similarly, the geometry of the output matrix, the multiplexer and the output ports determines uniquely the wavelengths on a certain port. However, the position of the mirrors may be adjusted with a control system, so that the path of a wavelength within the switch fabric is adjustable, so that a wavelength input on a port may output the switch on any port.

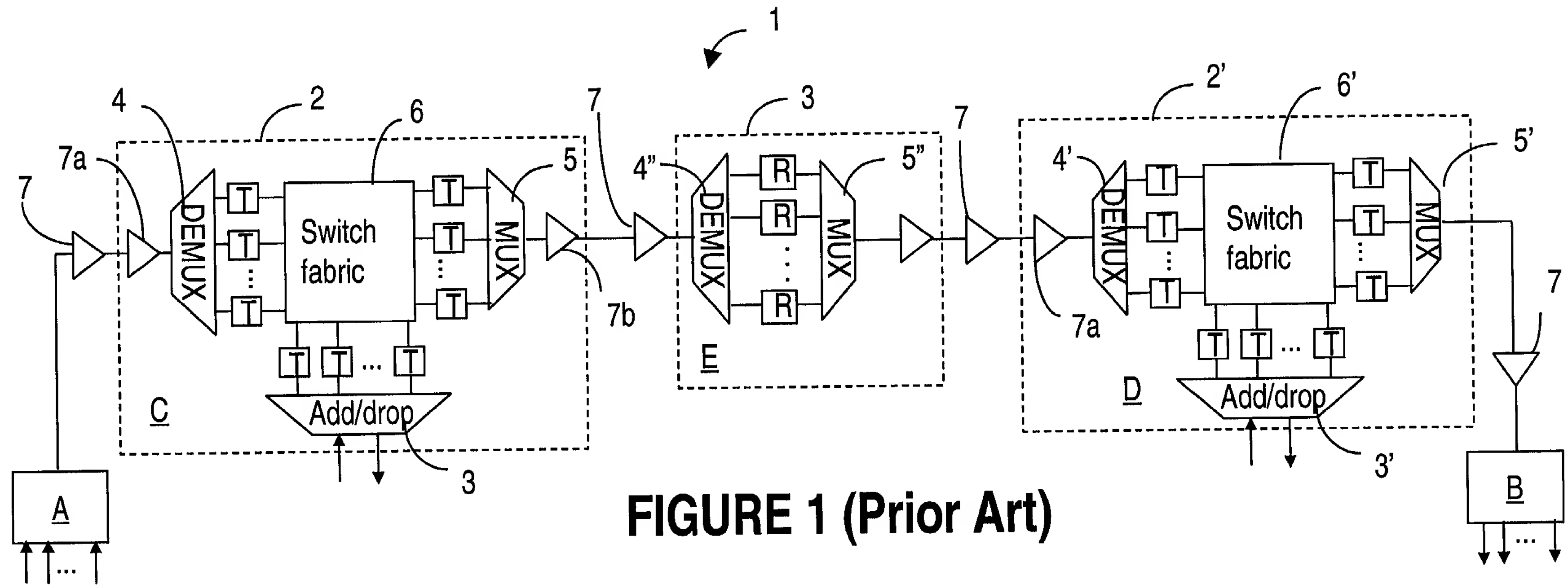


FIGURE 1 (Prior Art)

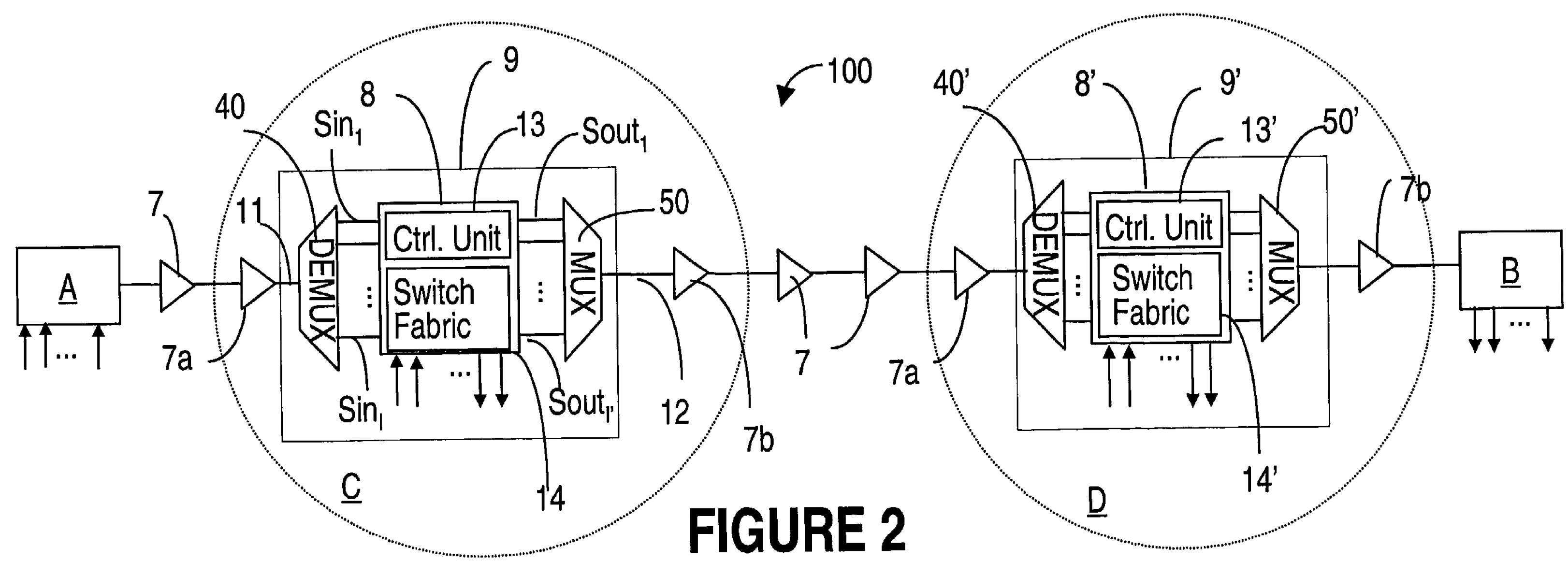
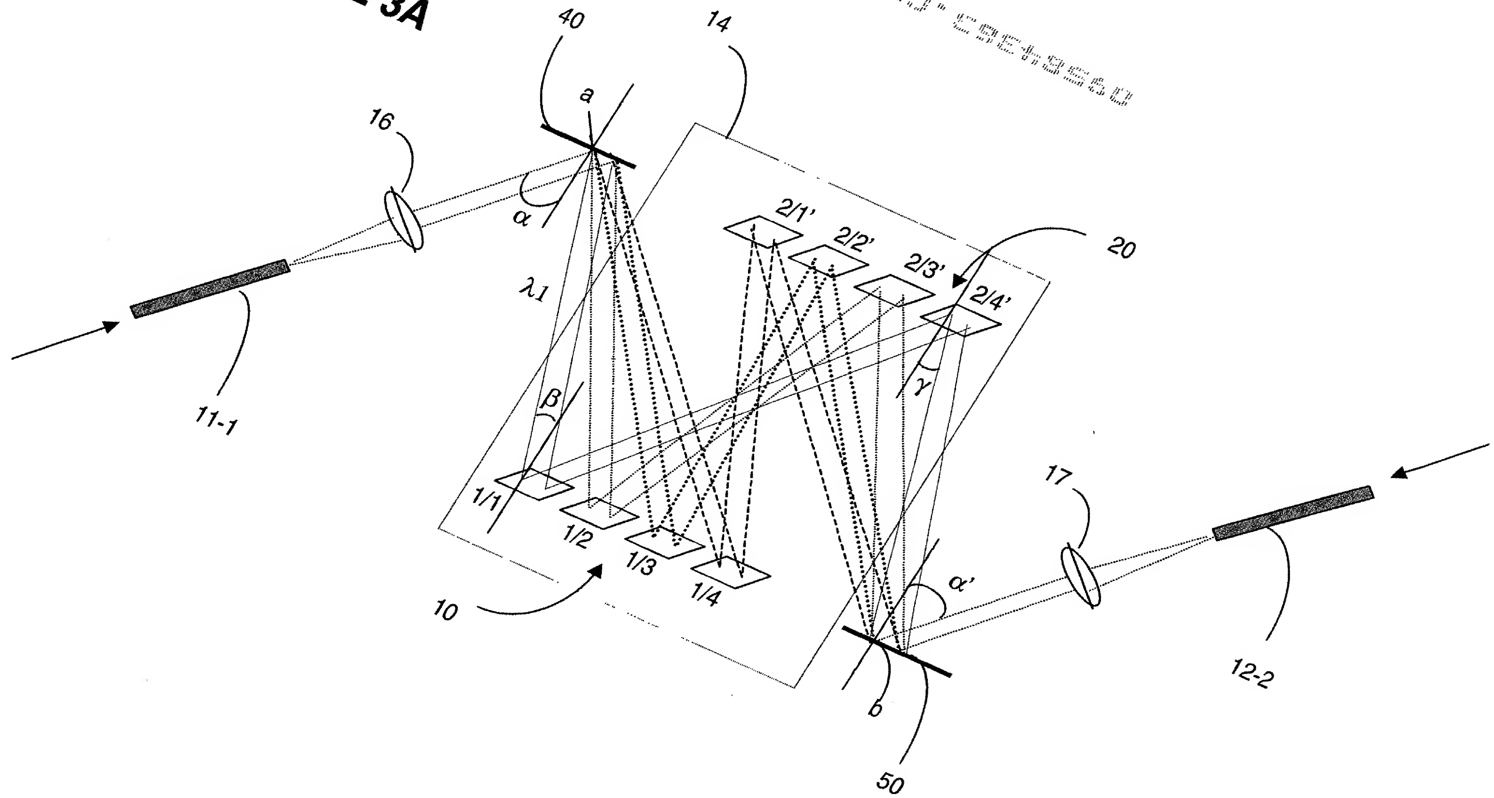
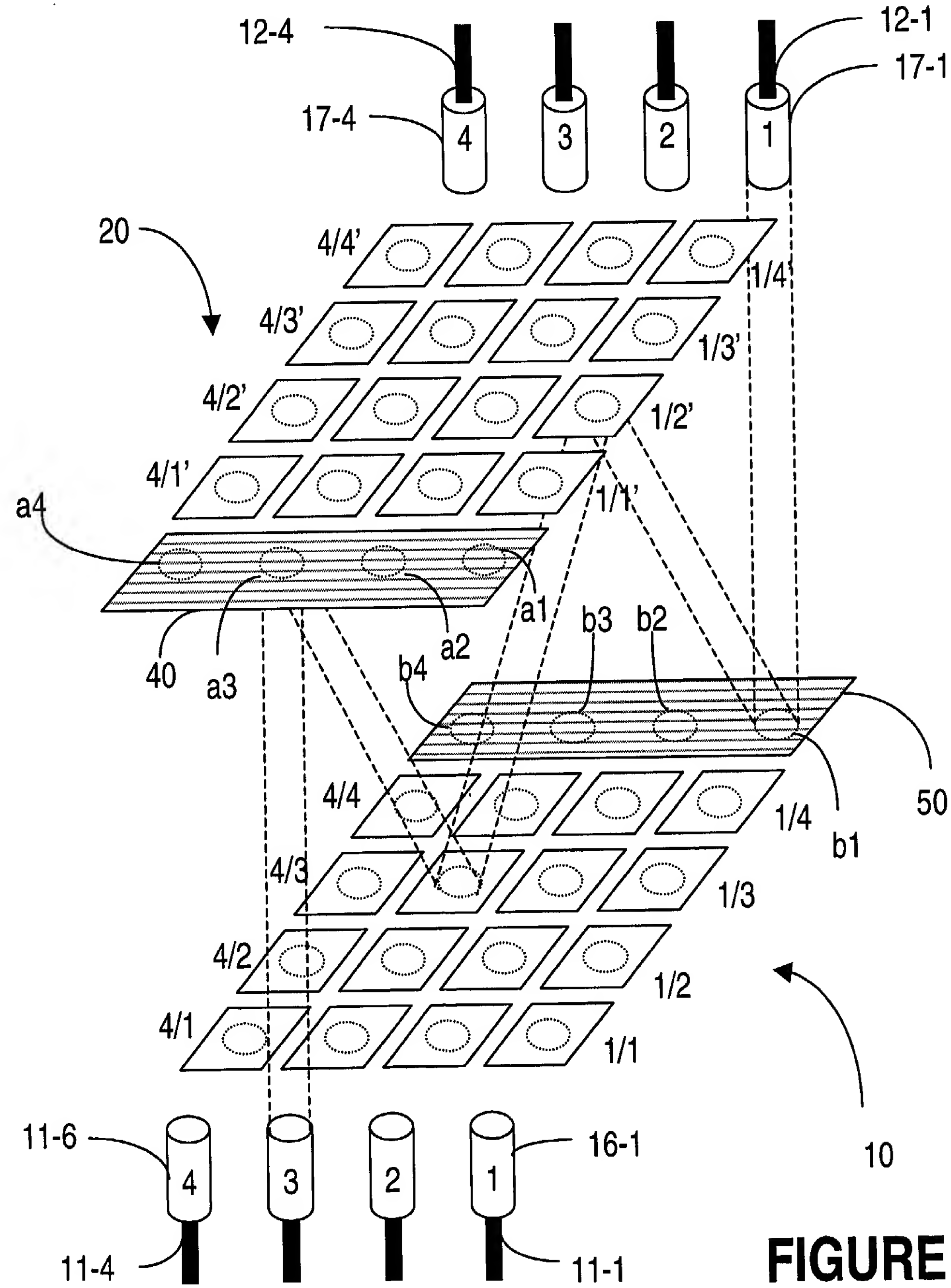


FIGURE 2

FIGURE 3A

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a3
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b1
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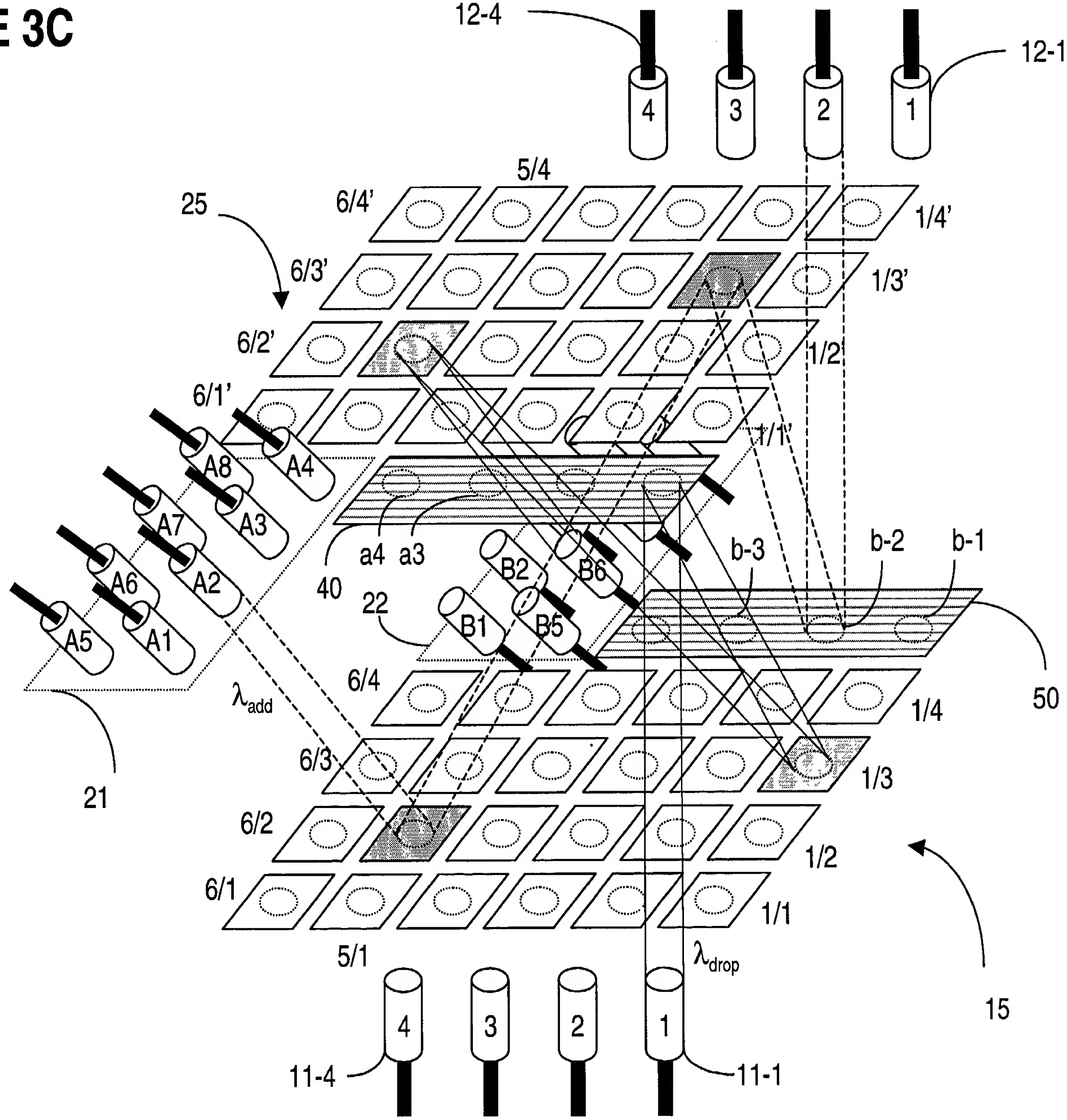
FIGURE 3B

FIGURE 3C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A7
A3
A6
A2
A5
A1
40
a4
a3
B2
B6
B1
B5
22
b-3
b-2
b-1
50
21
λ_{add}
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11-1

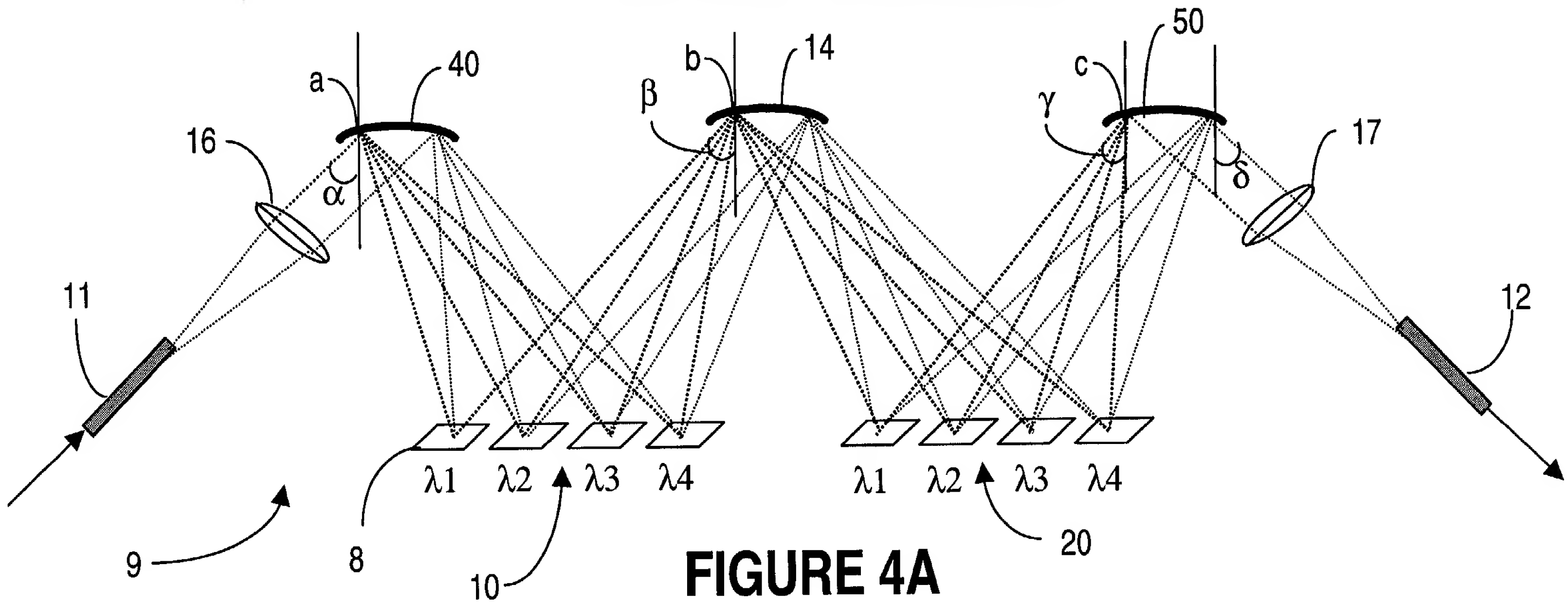

FIGURE 4A

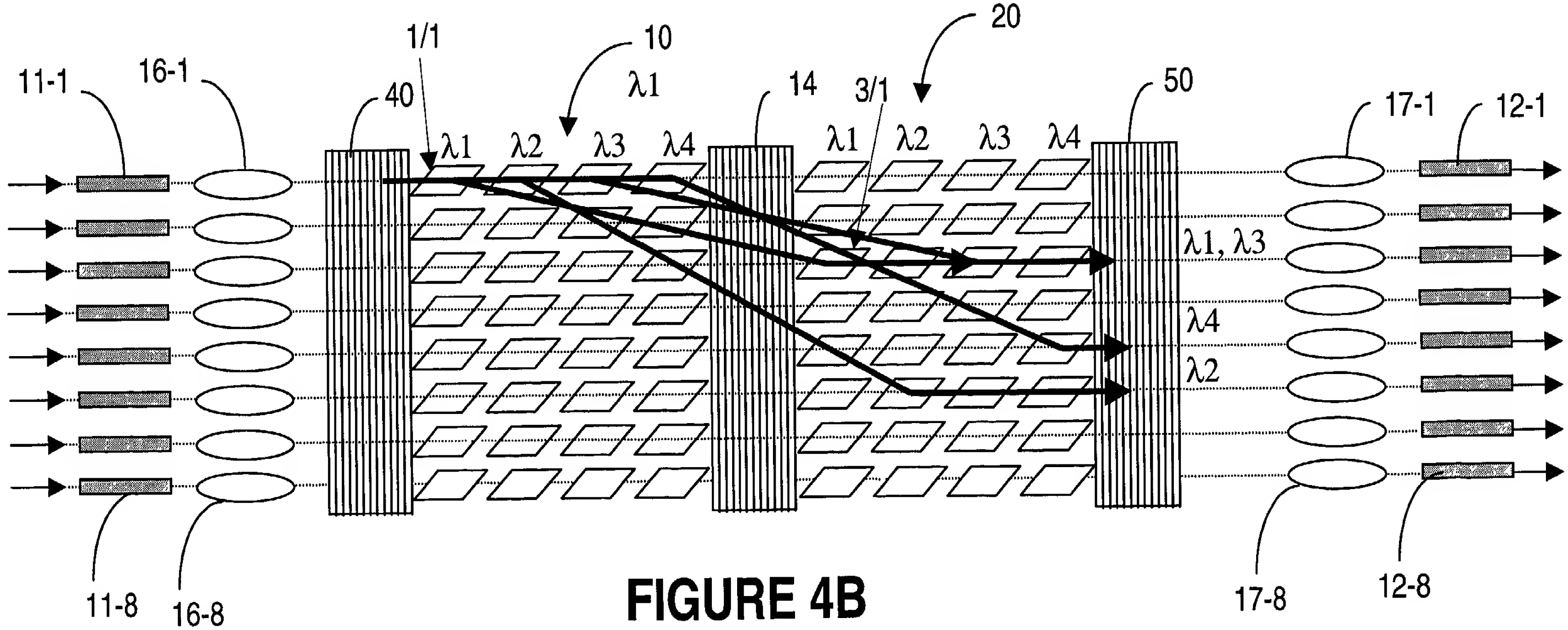

FIGURE 4B

DECLARATION FOR PATENT APPLICATION AND APPOINTMENT OF AGENT

Case: 11930ROUS02U

As a below-named Inventor, I hereby declare that:
My Residence, Post Office address and Citizenship are as stated below next to my name.

☐ I believe that I am the original, first and sole inventor
☒ I believe I am an original, first and joint inventor
of the subject matter which is claimed and for which a patent is sought on the invention entitled:

INTEGRATED PHOTONIC SWITCH

the Specification of which
☒ is attached hereto
☐ was filed on ____________ as U.S. Application or PCT International Application No. ____________
☐ and was amended on ____________ (if applicable)

I hereby state that I have reviewed and understand the contents of the above-identified Specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to the Examination of the Application in accordance with Title 37, Code of Federal Regulations, §1.56.

I hereby claim foreign priority benefits under Title 35, United States Code, §119(a)-(d) of any foreign Application(s) for Patent or Inventor's Certificate listed below and have also identified below any foreign Application for Patent or Inventor's Certificate having a filing date before that of the Application on which priority is claimed:

PRIOR FOREIGN APPLICATION(S)

Number	Country	Date Filed	Priority Claimed
not yet available	CANADA	March 15, 2000	X

I hereby claim the benefit under Title 35, United States Code, §119(e) of any United States provisional Application(s) listed below.

Application Number	Date Filed
n/a	

I hereby claim the benefit under Title 35, United States Code, §120 of any United States Application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States Application in the manner provided by the first paragraph of Title 35, United States Code, §112, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, §1.56 which occurred between the filing date of the prior application and the National or PCT International filing date of the Application.

Application Number	Date Filed	Status
n/a		

I hereby appoint **Aprilia U. Diaconescu** c/o Nortel Networks Corporation, Intellectual Property Law Group, P.O. Box 3511, Station C, Ottawa, Ontario, Canada, K1Y 4H7, Registration No. **37,989** and telephone no. (613) 768-3009 as my Agent to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true, and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the Application or any Patent issued thereon.

Full Name of First or Sole Inventor: Frederick J. LALONDE	Signature of First Inventor: Fred LaLonde	Date: 4/4/2000
Residence Address: 141A Tercy Street, Ottawa, Ontario K1R 6C8 CANADA		Country of Citizenship: CANADA
Post Office Address: SAME AS ABOVE		

Full Name of Second Inventor (if any): Peter D. ROORDA	Signature of Second Inventor: P Roorda	Date: March 27, 2000
Residence Address: 15 The Chestnuts, Hertford, Hertfordshire, ENGLAND SG13 8AQ		Country of Citizenship: CANADA
Post Office Address: SAME AS ABOVE		

Full Name of Third Inventor (if any): Alan Glen SOLHEIM	Signature of Third Inventor: Alan Solheim	Date: April 17/2000
Residence Address: 56 Huntsman Crescent, Kanata, Ontario K2M 1C4 CANADA		Country of Citizenship: CANADA
Post Office Address:		

Signatures should conform to names as typewritten. ☐ Additional inventors on attached Page 2

Form NTP (0499)